

INTERACTIONS OF NEGATIVE K MESONS
IN FLIGHT IN NUCLEAR EMULSION

Frank Hunter Featherston

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IN NUCLEAR EMULSION

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Frank Hunter Featherston

INTERRELATIONS OF THE FLIGHT MECHANISMS IN FLIGHT
IN FLIGHT EMULSION

RESEARCH REPORT NO. 100

INTERACTIONS OF NEGATIVE K MESONS IN FLIGHT
IN NUCLEAR EMULSION

by
Frank Hunter Featherston

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE
IN
PHYSICS

United States Naval Postgraduate School
Monterey, California

1957

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INTERRELATIONS OF THE ACTIVE PERSON IN THE
INDUSTRIAL REVOLUTION

Frank H. Johnson

San Diego, California
of the University of California

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United States National Academy of Sciences
Montgomery, California

1915

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IN NUCLEAR EMULSION

by

Frank Hunter Featherston

This work is accepted as fulfilling
the thesis requirements for the degree of

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UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

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INTERACTIONS OF NEGATIVE K MESONS IN FLIGHT
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Frank Hunter Featherston

(M. S. Thesis)

April 30, 1957

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INTERACTIONS OF NEGATIVE K MESONS IN A LIGHT
IN NUCLEAR EMULSION

Frank Hunter Ferguson

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INTERACTIONS OF NEGATIVE K MESONS IN FLIGHT IN NUCLEAR EMULSION

Frank Hunter Featherston

Radiation Laboratory
University of California
Berkeley, California

April 30, 1957

ABSTRACT

A survey of interactions of K^- mesons in flight in nuclear emulsion has been made. Seventy-seven in-flight interactions, seven decays in flight, and four inelastic scatterings were found.

A K^- meson mean free path in nuclear emulsion of 30.0 ± 3.0 cm has been calculated.

A K^- -meson lifetime of $1.31^{+.38}_{-.28} \times 10^{-8}$ sec has been calculated.

All interactions were consistent with the conservation of strangeness.

A general qualitative comparison is made between the in-flight and at-rest interactions of K^- mesons.

Two decays in flight were measured, one leading to a definite establishment of a $K^-_{\pi 2}$ decay mode, the other to a strong suggestion of a $K^-_{\mu 2}$ mode.

The angular distribution of the decay pions from 37 Σ hyperons produced by K^- interactions is reported. The distribution tends towards isotropy.

THE EFFECTS OF ILLUMINATION ON NUCLEAR REACTION

Frank Hunter, Jr.

Radiation Laboratory
University of California
Berkeley, California

April 30, 1954

ABSTRACT

A series of measurements of the reaction $n + {}^{13}\text{C} \rightarrow {}^{14}\text{C} + \gamma$ have been made in which the intensity of the incident neutron beam was varied over a range of 10^4 to 10^6 neutrons/cm². The results show that the reaction rate is proportional to the square of the neutron intensity, indicating a second-order reaction. The energy of the γ rays was measured and found to be 4.78 ± 0.05 MeV. The angular distribution of the γ rays was also measured and found to be isotropic. The results are compared with the theoretical predictions of the reaction $n + {}^{13}\text{C} \rightarrow {}^{14}\text{C} + \gamma$.

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Out of a welter of early results and symbols, the heavy mesons have come to be known as the K mesons. This assignment of a definite name to these mesons by no means connotes the same unanimity and simplicity of characteristics and properties as are associated with the older well-established particles. In truth, within the realm of K mesons, it has been found necessary to present a more precise listing of these particles, based first, of course, upon electric charge, but more importantly, upon the several ways in which the K meson can decay (more properly, a phenomenological classification).

On this basis the so-called heavy or K mesons, can be listed as follows, with the decay modes indicated [1, 2]:

$$K^+_{\pi 3}, \tau^+$$

$$\tau^+_{\mu 2}$$

$$K^+_{\mu 2}$$

$$K^+_{\pi 2}, \theta^+$$

$$K^+_{\mu 3}$$

$$K^+_{e 3}$$

$$K^+ \rightarrow \pi^+ + \pi^- + \pi^+$$

$$K^+ \rightarrow \pi^+ + \pi^0 + \pi^0$$

$$K^+ \rightarrow \mu^+ + \nu$$

$$K^+ \rightarrow \pi^+ + \pi^0$$

$$K^+ \rightarrow \mu^+ + \pi^0 + \nu$$

$$K^+ \rightarrow e^+ + ? + ?$$

$$\theta^0, \theta^0_1 (?)$$

$$\theta^0, \theta^0_2 (?)$$

$$K^0 \rightarrow \pi^+ + \pi^-$$

$$(K^0 \rightarrow \pi^0 + \pi^0)$$

$$K^0 \rightarrow \pi^\pm + e^\mp + \nu$$

$$K^0 \rightarrow \pi^\pm + \mu^\mp + \nu (?)$$

$$K^-_{\pi 2}$$

$$K^-_{\mu 2}$$

$$K^-_{\mu 3}$$

$$K^-_{e 3}$$

$$K^-_{\pi 3}, \tau^-$$

$$K^- \rightarrow \pi^- + \pi^0$$

$$(K^- \rightarrow \mu^- + \nu)$$

$$(K^- \rightarrow \mu^- + \pi^0 + \nu)$$

$$K^- \rightarrow e^- + (?) + (?)$$

$$K^- \rightarrow \pi^- + \pi^- + \pi^+$$

$$(K^- \rightarrow \pi^- + \pi^0 + \pi^0)$$

Out of a whole lot of things, I think I can say that I have

increased my knowledge of the world, and I have also learned a

little more about the things that are going on in the world.

meanwhile, I have also learned a little more about the things that

are going on in the world, and I have also learned a little more

about the things that are going on in the world, and I have also

learned a little more about the things that are going on in the

world, and I have also learned a little more about the things that

are going on in the world, and I have also learned a little more

about the things that are going on in the world.

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that are going on in the world, and I have also learned a little

more about the things that are going on in the world.

meanwhile, I have also learned a little more about the things that

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Out of a welter of early results and symbols, the heavy mesons have come to be known as the K mesons. This assignment of a definite name to these mesons by no means connotes the same unanimity and simplicity of characteristics and properties as are associated with the older well-established particles. In truth, within the realm of K mesons, it has been found necessary to present a more precise listing of these particles, based first, of course, upon electric charge, but more importantly, upon the several ways in which the K meson can decay (more properly, a phenomenological classification).

On this basis the so-called heavy or K mesons, can be listed as follows, with the decay modes indicated [1, 2]:

$K^+_{\pi 3}, \tau^+$	$K^+ \rightarrow \pi^+ + \pi^- + \pi^+$
$\tau^+_{\pi 3}, \tau^+$	$K^+ \rightarrow \pi^+ + \pi^0 + \pi^0$
$K^+_{\mu 2}$	$K^+ \rightarrow \mu^+ + \nu$
$K^+_{\pi 2}, \theta^+$	$K^+ \rightarrow \pi^+ + \pi^0$
$K^+_{\mu 3}$	$K^+ \rightarrow \mu^+ + \pi^0 + \nu$
$K^+_{e 3}$	$K^+ \rightarrow e^+ + ? + ?$
$\theta^0, \theta^0_1 (?)$	$K^0 \rightarrow \pi^+ + \pi^-$
$\theta^0, \theta^0_2 (?)$	$(K^0 \rightarrow \pi^0 + \pi^0)$
	$K^0 \rightarrow \pi^\pm + e^\mp + \nu$
	$K^0 \rightarrow \pi^\pm + \mu^\mp + \nu (?)$
$K^-_{\pi 2}$	$K^- \rightarrow \pi^- + \pi^0$
$K^-_{\mu 2}$	$(K^- \rightarrow \mu^- + \nu)$
$K^-_{\mu 3}$	$(K^- \rightarrow \mu^- + \pi^0 + \nu)$
$K^-_{e 3}$	$K^- \rightarrow e^- + (?) + (?)$
$K^-_{\pi 3}, \tau^-$	$K^- \rightarrow \pi^- + \pi^- + \pi^+$
	$(K^- \rightarrow \pi^- + \pi^0 + \pi^0)$

1. The first part of the paper is devoted to the

study of the properties of the

operator T defined by

$$Tf(x) = \int_0^x f(t) dt$$

for $f \in L^p(\mathbb{R})$, $1 < p < \infty$.

It is shown that T is a bounded operator on $L^p(\mathbb{R})$ and

that its norm is equal to 1.

2. The second part of the paper is devoted to the

study of the properties of the operator S defined by

$$Sf(x) = \int_0^x f(t) dt$$

for $f \in L^p(\mathbb{R})$, $1 < p < \infty$.

It is shown that S is a bounded operator on $L^p(\mathbb{R})$ and

that its norm is equal to 1.

3. The third part of the paper is devoted to the

study of the properties of the operator R defined by

$$Rf(x) = \int_0^x f(t) dt$$

for $f \in L^p(\mathbb{R})$, $1 < p < \infty$.

It is shown that R is a bounded operator on $L^p(\mathbb{R})$ and

that its norm is equal to 1.

4. The fourth part of the paper is devoted to the

study of the properties of the operator Q defined by

$$Qf(x) = \int_0^x f(t) dt$$

for $f \in L^p(\mathbb{R})$, $1 < p < \infty$.

It is shown that Q is a bounded operator on $L^p(\mathbb{R})$ and

that its norm is equal to 1.

5. The fifth part of the paper is devoted to the

study of the properties of the operator P defined by

$$Pf(x) = \int_0^x f(t) dt$$

for $f \in L^p(\mathbb{R})$, $1 < p < \infty$.

It is shown that P is a bounded operator on $L^p(\mathbb{R})$ and

In this listing, the symbol shown on the left of each decay mode is the presently accepted code by which each of the decay modes is designated. The " τ " and " θ " symbols have persisted from the earlier and original designations of these particular decay modes of the K meson. Those decay modes in parentheses have not actually been observed, but are to be expected from charge symmetry.

Strangeness

From this formidable listing of K-meson decay modes, one could quite properly ask whether we are witnessing the decay of two or more different particle species or whether we are seeing the several decay modes of a single species of particle, as the "K" designation implies.

This first question of the multiplicity of decay of the K meson is quickly joined by another experimental puzzle. Both hyperons and heavy mesons are abundantly produced in high-energy nuclear interactions, which means copious production on a time scale of the order of 10^{-23} sec; yet the lives of these particles, once they are produced, are very long by comparison ($\sim 10^{-8}$ to $\sim 10^{-10}$ sec). This discrepancy of approximately 10^{13} units of time scale is a seeming contradiction of reversibility principles, by which one would expect the decay of these particles in something akin to 10^{-23} second.

A suitable explanation of these effects began to take form in 1952 when Pais proposed that heavy mesons and hyperons can be produced only in pairs, i. e., in association with each other [3]. This associated production scheme indicated that there are certain selection rules that prevent strong interactions from being operative as part of the decay mechanism.

Finally in 1954, Gell-Mann, Nishijima, and others put forth the hypothesis that explained the apparent dilemma [4]. They

in the following: the symbol α is used to denote the
matrix is the present case, and β is used to denote the
is designated. The "T" and "U" symbols have been used
earlier and different designations of these parameters have been used
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Symptoms

1. The first form of the K-matrix is the one
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introduced a new property of matter, "strangeness," and stipulated certain selection rules based upon the assignment of a new quantum number to each of the particles in a process (this new number itself they called "strangeness", S). Certain properties of this new number were that it (1) must be integral, (2) could be either positive or negative, and (3) would be a constant of motion in strong interactions, but would change by ± 1 in weak interactions.

From this scheme of things, particle-interaction processes were divided into three classes:

a. Fast Interactions (i.e., direct production)

- (1) time scale $\sim 10^{-23}$ sec.
- (2) satisfaction of all conservation laws (energy, momentum, angular momentum, parity, charge, heavy particle number, and strangeness). Thus, $\Delta S = 0$.
- (3) process does not include emission of a gamma ray.

b. Electromagnetic Interactions

- (1) involve the emission of a gamma ray.
- (2) weaker by $1/137$ than the fast reactions
- (3) proceed on a time scale of $\sim 10^{-17}$ sec.

c. Slow Interactions

- (1) decays
- (2) proceed on a time scale of 10^{-10} sec.
- (3) can violate parity considerations
- (4) $\Delta S = \pm 1$

Thus, (a) would be the strong interactions which involve baryons, antibaryons, and mesons. We are here in the region of fully nuclear forces, in which mesons and hyperons are produced in high-energy nuclear interactions. The electromagnetic interaction (b) is the natural mechanism whereby the photon involves itself with all charged particles.

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proof of work and solving saw

Incubated at 28°C in 100% humidity for 24 h.

1942-1943

0. Theorem 1. If μ is a probability measure, it is not null if and only if

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0-60 mph in 17 sec. 100-gph fuel tank

the following: $\mathbf{A} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $\mathbf{B} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$, $\mathbf{C} = \begin{pmatrix} 1 & 1 \\ 0 & 0 \end{pmatrix}$, $\mathbf{D} = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$.

of a very important kind

1. *Phragmites australis* (Cav.) Trin. ex Steud.

$$= (0, 1) \cup \{1\} \cup (1, 2) \cup \{2\} \cup (2, 3) \cup \{3\} \cup (3, 4) \cup \{4\} \cup (4, 5) \cup \{5\} \cup (5, 6) \cup \{6\} \cup (6, 7) \cup \{7\} \cup (7, 8) \cup \{8\} \cup (8, 9) \cup \{9\} \cup (9, 10) \cup \{10\} \cup (10, 11) \cup \{11\} \cup (11, 12) \cup \{12\} \cup (12, 13) \cup \{13\} \cup (13, 14) \cup \{14\} \cup (14, 15) \cup \{15\} \cup (15, 16) \cup \{16\} \cup (16, 17) \cup \{17\} \cup (17, 18) \cup \{18\} \cup (18, 19) \cup \{19\} \cup (19, 20) \cup \{20\} \cup (20, 21) \cup \{21\} \cup (21, 22) \cup \{22\} \cup (22, 23) \cup \{23\} \cup (23, 24) \cup \{24\} \cup (24, 25) \cup \{25\} \cup (25, 26) \cup \{26\} \cup (26, 27) \cup \{27\} \cup (27, 28) \cup \{28\} \cup (28, 29) \cup \{29\} \cup (29, 30) \cup \{30\} \cup (30, 31) \cup \{31\} \cup (31, 32) \cup \{32\} \cup (32, 33) \cup \{33\} \cup (33, 34) \cup \{34\} \cup (34, 35) \cup \{35\} \cup (35, 36) \cup \{36\} \cup (36, 37) \cup \{37\} \cup (37, 38) \cup \{38\} \cup (38, 39) \cup \{39\} \cup (39, 40) 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[illegible]

5. 10. 1991

1. The first step is to identify the problem or question that needs to be answered.

and the following relation also is satisfied

22 (B)

submit your - and mine - We are pleased to have you as a member of the

for the treatment of hypertension and hyperlipidemia.

mechanism which the polymer chain is bound to follow.

The slow (or weak) interactions (c) are the beta-decay process, the various heavy-meson and hyperon decays, and μ -mesonic absorption and decay.

The assignment of strangeness quantum numbers to the various particles is as follows:

$$\begin{array}{ll}
 S = 0: & p, n; \pi^+, \pi^0, \pi^- \\
 S = 1: & K^0, K^+ \\
 S = -1: & K^-, \bar{K}^0; \Lambda^0; \Sigma^+, \Sigma^0, \Sigma^- \\
 S = -2: & \overline{\Lambda}^0, \overline{\Sigma}^-
 \end{array}$$

It is well to remember that two charge-conjugate particles must have equal and opposite values of S , because in a fast interaction a particle can be transposed to the other side of the reaction and become its own antiparticle without changing the fast nature of the reaction.

One finds the most direct experimental support of strangeness from a consideration of the charge degeneracy of strange-particle states and the z th component of the isotopic spin. From π -meson physics there comes an expression relating these:

$$Q - I_z - N/2 = 0,$$

where Q is the charge,

I_z is the third component of the isotopic spin,

N is the number of nucleons.

If, through some mechanism in strange-particle interactions, the conservation of isotopic spin remains but the above relation does not hold, i. e. ,

$$Q - I_z - N/2 \neq 0,$$

then this sum must still be a quantity that is additively conserved, since Q , I_z , and N are all conserved separately. Thus, the basis of the strangeness scheme is a postulation that a new quantum number,

$$S = 2(Q - I_z - N/2),$$

can correlate and explain the strange-particle interactions.

An illustrative test of this is readily found in the Σ hyperons. The Σ^- has $S = -1$, $Q = -1$, and $N = 1$. I_z thus equals -1 . This indicates that there must be two additional particles of mass similar to that of the Σ^- , with $I_z = 0$ and 1 , and $Q = 0$ and $+1$, respectively. Experiment has found two such particles satisfying these conditions, Σ^0 and Σ^+ .

The consistency of its explanations has been the remarkable feature of the strangeness concept. There are no known violations of the strangeness-selection rules. Associated production, too, appears to be the order of business. As an explanation, the scheme has done yeomen's service in pointing the way through the dense underbrush of much contemporary research.

Nuclear Emulsions as a Research Tool

The techniques of high-energy particle research are necessarily of a very specialized nature. There are four general experimental systems used in high-energy particle research,

- (1) nuclear photographic emulsions,
- (2) cloud chambers,
- (3) bubble chambers,
- (4) scintillating and electronic counting networks.

Each of the four systems has both advantages and limitations peculiar to itself. Employment of a given system in a specific application may enhance or diminish certain of its capabilities.

As a stopping medium, nuclear emulsions are the heaviest by far of the investigative media, having a density of about 3.85 g/cc (average density of Ilford G. 5 emulsion) [5]. The basic elemental constituents of such an emulsion, with the corresponding approximate percentage compositions, by weight, are [5]:

Silver	47.5%	Hydrogen	1.4%
Bromine	35.0	Oxygen	6.5
Iodine	0.3	Nitrogen	1.9
Carbon	7.2	Sulfur	0.2

As a research tool, the emulsion provides a means for direct visual survey and measurement of the tracks left by ionizing particles as they pass through the emulsion stack. (Neutral particles of course, leave no tracks.)

A particle entering an emulsion may

- (1) Suffer energy degradation and slowing down, but succeed in leaving the emulsion; or
- (2) interact (or annihilate) with one of the constituent elemental nuclei while in flight; or
- (3) while in flight in the emulsion, decay, with the resulting particle(s) continuing on in the emulsion; or
- (4) be progressively slowed down until it comes to rest in the emulsion. Characteristically, then, the particle can either (if negative) be absorbed into a constituent nucleus, or (if positive) decay.

With a proper selection of physical parameters, an emulsion stack provides a wonderfully compact and portable means for observing the in-flight and terminal behavior of ionizing particles. Also, because of its great stopping power, the nuclear emulsion is a useful device for coping with short-lived particles when one is attempting to obtain a

measure of mean lifetime of the order of 10^{-8} to 10^{-13} sec. This is made possible through the greater density of the medium, which causes many of the particles to come to rest before they decay.

As one of the oldest of high-energy particles research systems, the art of employing nuclear emulsions has given rise to many refined auxiliary techniques. Through the use of these techniques one is able to

- (1) make an exhaustive analysis of specific and unusual events,
- (2) make very accurate mass determinations,
- (3) accomplish ready and reliable identification of particles,
- (4) precisely predict the response of the system to ionizing particles of any mass (this makes the emulsion well suited for exploratory detection attempts [6]),
- (5) make accurate ionization measurements.

The one important factor to appreciate when considering nuclear emulsion results is that the interacting nuclei of the emulsion proper are of several types, covering a wide range of atomic numbers. Silver and bromine nuclei are by far the most numerous and the heaviest, with an average A of 94. Hence, any discussion of emulsion results will be conditioned by this fact. This is not, as might be hastily inferred, a completely deleterious effect; for as pleasant-appearing as the simpler interaction phenomena of the bubble chambers may appear, particle interactions in complex nuclei have a definite appeal of their own.

II. GENERAL EXPERIMENTAL METHOD

Exposure and Development

This comprehensive study of a group of K^- mesons in flight interactions in nuclear emulsion is a modest (but typical) example of the directed application of research effort, made possible by the availability of relatively intense beams of artificially produced K mesons from the Bevatron.

In this instance an emulsion stack of Ilford G. 5 stripped nuclear emulsion, composed of 108 pellicles, each 4 by 7 inches and 600 microns thick, was exposed to a momentum-selected K^- beam of 420 Mev/c. Momentum selection was accomplished by utilizing the magnetic field of the Bevatron itself; quadrupole lenses were used to increase the intensity of the beam. This exposure was the cooperative effort of Gerson and Sulamith Goldhaber and Warren W. Chupp at the Berkeley Bevatron.

The beam to which the stack was exposed contained a mixture of both negative π mesons and the desired K^- mesons (in the approximate ratio of 3000 to 1). The π mesons presented ionization tracks of near-minimum intensity in the emulsion at this particular momentum; hence, they provided a convenient built-in comparative measure of ionization.

The K^- beam was emitted at 0° relative to the target. The beam was lead undeviated through the quadrupole focusing system, which meant that a background of contamination could appear in the exposure because of spurious products produced by portions of the beam striking the yokes of the focusing magnets. To remove this source of contamination, a sweeping magnet was placed behind the quadrupole system to remove all positive particles (i. e., protons).

Exposure and Measurement

This comprehensive study of the group of K⁺ ions in high energy interactions in the field of a nucleus is a very complex example of the method of the study of the interaction of the K⁺ ions with the nucleus. The study of the interaction of the K⁺ ions with the nucleus is a very complex example of the method of the study of the interaction of the K⁺ ions with the nucleus.

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The K⁺ beam was emitted at a very high energy. The study of the interaction of the K⁺ ions with the nucleus is a very complex example of the method of the study of the interaction of the K⁺ ions with the nucleus. The study of the interaction of the K⁺ ions with the nucleus is a very complex example of the method of the study of the interaction of the K⁺ ions with the nucleus.

The emulsion stack was aligned for exposure so that its long dimension was longitudinally placed in the beam. Thus, the particle tracks were parallel to the emulsion layers; the mean range of K^- mesons of this momentum (10.2 cm) was, conveniently, about two-thirds the length of the plate.

Development of the stack followed a modified "Bristol" procedure. Subsequent location of the "x" and "y" coordinates of a given position within each plate-mounted pellicle was facilitated by the contact printing of a grid system of coordinates on the surface of the emulsion, with numbered grids occurring every millimeter [7].

Scanning and Measurement

Inspection of the plate-mounted and developed layers of a photographic nuclear emulsion is accomplished with high-resolution microscopes. This "scanning" can be executed by following either of two general techniques: (1) area scanning, in which the observer looks at all events within a given area of the plate, looking for interaction stars, and subsequently following the causative particle back from the event to where it entered the emulsion; (2) along-the-track scanning, in which scanning is done transversely across the beam of entering particle tracks near the edge of the plate. On the readily determined basis of their relative degree of ionization, tracks of the appropriate ionization can be followed and their terminal behavior recorded.

Along-the-track scanning introduces a minimum of bias towards finding or rejecting any particular species of terminal behavior. All types of track endings are seen with equal facility, since all tracks are followed from where they enter the emulsion, before an event occurs. Area scanning, on the other hand, must--by the nature of the technique and from the inevitable human considerations involved--result in not seeing all the events with no secondaries or with light,

minimal secondaries. Area scanning has its place under certain circumstances (cosmic-ray exposures, or surveys for particular types of interactions or interaction products, for example).

In the exposure study made in gathering the data for this report, transverse scanning near the exposed edge of the plates readily revealed those particles with a degree of ionization approximately 1.8 times minimum, the theoretically predictable degree of ionization characteristic of K^- mesons of the selected momentum in Ilford G.5 emulsion.

Each track so selected was followed to its end in the emulsion. Every reported event was unambiguously identified as being caused by a K^- meson, either by successive grain counts (ionization measurements) if sufficient track length was available, or by multiple-scattering techniques, utilizing the constant-sagitta method, to obtain a measure of the particle's $p\beta$, to be compared with its relative ionization.

All interaction products were followed either to their endings or until they left the stack. All prongs not identifiable as electrons, mesons, hyperons, or hyperfragments were termed "stable charged" prongs and were assigned kinetic energies from their measured ranges upon the assumption of a protonic mass. This leads to a resulting underestimate of the kinetic energy of approximately one third of the particles, which are actually deuterons, tritons, alpha particles, or recoil fragments. All prongs less than 5 microns long were termed "recoils" and were not considered in either prong or energy distributions.

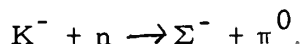
III. RESULTS

Summary

All together, seventy-seven interactions in flight of K^- mesons have been identified. Seven additional events were identified as decays in flight of K^- mesons; four other events have been established as representing the inelastic scattering of K^- mesons by the constituent nuclei of the emulsion.

Of the 77 in-flight events, 13 produced charged Σ hyperons, 10 of which had visible associated π mesons. Three events produced charged Σ hyperons without any visible π mesons. Similarly, 12 events produced π mesons without identifiable Σ hyperons. Thus, 17% of the event produced identifiable Σ hyperons; 29% of the events produced π mesons; 13% of the events produced visible Σ hyperons and π mesons in association.

Of the 13 Σ 's seen, two were Σ^- , five were Σ^+ , and six decayed in flight and hence could be either Σ^+ or Σ^- . Of these six, one could be considered Σ^- because the Σ itself was the sole visible reaction product; thus, there is a possibility that the interaction went via the available channel:



One star produced a hyperfragment, which decayed nonmesically.

One of the ten observed $\Sigma + \pi$ events was established as representing the capture of a K^- meson in hydrogen [8].

Forty-eight of the events produced only charged stable, i. e., "evaporation", prongs.

Three of the K^- tracks ended in flight with no visible prongs. These are classified as disappearances and are included in the total of 77.

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in flight and the isolation of the individual according to the degree of its involvement in the process.

[illegible]

in the case of the channel.

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These results represent a scanning effort of 25.71 meters of K^- meson track (in which, in addition, 226 K^- -meson absorptions at rest have been identified)[9]. This figure for track length includes two corrective factors: (1) The last 2 mm of each track that comes to rest (corresponding to the last 16 Mev of kinetic energy) have been omitted from consideration because a decay in flight in this region is difficult to identify; (2) The first 5 mm of each track have not been included because the primary particle causing an event in this early region cannot be easily identified as a K particle. Table I is a tabulation of the length of track scanned in the indicated energy intervals.

TABLE I

<u>Length of K^- Meson Track Scanned in Energy Intervals</u>	
<u>Energy Interval</u> (Mev)	<u>Track Length</u> (cm)
16 - 30	94.4
30 - 40	90.5
40 - 50	116.9
50 - 60	132.8
60 - 70	156.1
70 - 80	167.3
80 - 90	193.2
90 - 100	221.6
100 - 110	221.7
110 - 120	237.1
120 - 130	261.2
130 - 140	268.7
140 - 150	272.6
150 - 160	124.8
160 - 170	12.1
Total	25.71 meters

Mean Free Path of K^- Mesons in Nuclear Emulsion

When the track length and number of events of this report are combined with the corresponding data from Iloff[2], who reports 21 in-flight interactions in 4.90 meters of track, the mean free path in nuclear emulsion for K^- mesons is found to be

$$\lambda = 30.0 \pm 3.0 \text{ cm.}$$

This corresponds to a nuclear radius $R = (1.32 \pm 0.07 \times 10^{-13}) A^{1/3}$ cm.

Mean Lifetime of the K^- Meson

The mean lifetime of the K^- meson, τ_{K^-} , equals T/N , where T is the algebraic sum of the proper slowing-down times for each K^- track, calculated from where the particle is first registered to where it decays or interacts in flight, or up to a point 2 mm before it comes to rest. N is the total number of observed decays. T is calculated on the basis of the tables of Barkas and Young [10].

The results of this investigation show seven (7) decays in flight with a corresponding proper slowing-down time of 13.85×10^{-8} sec. Again, combining these results with those of Iloff et al. [11], who report 13 decays with a corresponding total proper slowing-down time of 12.4×10^{-8} sec, one obtains

$$\tau_{K^-} = 1.31^{+.38}_{-.28} \times 10^{-8} \text{ sec.}$$

(The error quoted is based on confidence limits for 68% probability for 20 events).

This mean life, of course, is a mixture of the several possible K^- decay modes. It is to be compared with

$$\tau_{K^-} = 1.49^{+.22}_{-.24} \times 10^{-8} \text{ sec,}$$

M. to R. by T. to L. M. to R. by T. to L.

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recently reported from the results of a counter experiment [12]. This counter-determined value is based on an experiment conducted four mean lives from the target; the value presented in this report is based on an investigation two mean lives from the target.

Interaction Considerations

The conservations of strangeness, charge, and heavy-particle number allow only the following one-nucleon interactions of K^- mesons at rest:

- (1) $K^- + p \rightarrow \Sigma^+ + \pi^-$,
- (2) $\quad \quad \rightarrow \Sigma^- + \pi^+$,
- (3) $\quad \quad \rightarrow \Sigma^0 + \pi^0$,
- (4) $\quad \quad \rightarrow \Lambda^0 + \pi^0$,
- (5) $K^- + n \rightarrow \Sigma^- + \pi^0$,
- (6) $\quad \quad \rightarrow \Sigma^0 + \pi^-$,
- (7) $\quad \quad \rightarrow \Lambda^0 + \pi^-$.

Certain types of two-pion reactions are allowed, but are negligible from phase-space considerations. Multiple nucleon capture also is allowed, but is considered to make only a small contribution ($\sim 10\%$) [9].

These interactions come about through the capture at rest of the K^- meson in a Bohr orbit of the atom, with subsequent absorption into the nucleus. These absorptions are strong ("fast") interactions, occurring in $\sim 10^{-23}$ sec. They must, of necessity, proceed with positive Q values.

For the $K^- + p$ reaction, (1) through (4), one must have clearly in mind the difference between capture of a K^- meson by a proton that is bound in the nucleus, and K^- capture by a free proton. The bound proton is moving in a nuclear potential distribution; consequently, when it captures a K^- meson, the reaction products must find their way free of the nucleus. Thus, their visible energies are modified by

Figure 1 shows the results of the first experiment. The counter data are plotted against the time of day. The data show a clear diurnal variation, with a maximum value of about 100 counts per hour occurring at midday and a minimum value of about 20 counts per hour occurring at midnight.

Interaction of variables

If there is an interaction between the variables, the results of the experiment will be affected. The following table shows the results of the experiment for different values of the variables.

(1)	$\mu = 100$
(2)	$\mu = 80$
(3)	$\mu = 60$
(4)	$\mu = 40$
(5)	$\mu = 20$
(6)	$\mu = 10$
(7)	$\mu = 5$

It can be seen from the table that the results of the experiment are affected by the value of the variable μ . The results show that the counter data are highest for $\mu = 100$ and lowest for $\mu = 5$.

The results of the experiment show that the counter data are highest for $\mu = 100$ and lowest for $\mu = 5$. This is due to the fact that the counter data are proportional to the value of μ .

The results of the experiment show that the counter data are highest for $\mu = 100$ and lowest for $\mu = 5$.

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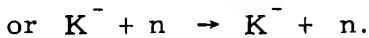
their escapes. The parent nucleus is also left in an excited state and will emit so-called "evaporation" prongs.

By contrast, K^- capture by a free proton displays none of these complications. The full Q of the reaction is carried away in the primary reaction products. Kinematic resolution of these events is thus possible through accurate measurement of the secondary tracks.

Comparison with K^+ Mesons

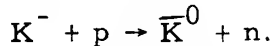
In addition to the K^- -absorption interactions listed in (1) through (7), the K^- meson is permitted to interact with matter while in flight by two additional mechanisms.

- a. Scattering, as permitted by



This scattering corresponds to inelastic scattering from a nucleus, but in scattering from hydrogen, elastic scattering is also possible.

- b. Charge exchange, wherein

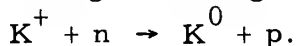


It is in these types of interaction, i. e., scattering and charge exchange, that positive K mesons display an exact correspondence to negative K -meson interaction types. Thus, the following K^+ meson interactions in flight are permitted:

- a. Scattering:



- b. Charge Exchange:



Because K^+ mesons have a strangeness value of +1, they are forbidden from undergoing absorption interactions corresponding to

their escapes. The present number is also not a scattered state and will emit so-called "evaporated" particles.

By contrast, the K^0 is captured by a free proton in a $K^0 p$ interaction. The full Q of the reaction is carried away in the proton. This many result in free K^0 (information on the reaction is not available) and thus possible through some mechanism of the reaction.

Comparison with K^0 Mesons

In addition to the K^0 meson, the interactions listed in (1) are also (2) the K^0 meson is in the interaction with matter which is different by two additional mechanisms.

a. Scattering, as per (1)

$$K^0 + p \rightarrow K^0 + p$$

$$K^0 + n \rightarrow K^0 + n$$

This scattering corresponds to the K^0 scattering from nucleons, b. In scattering from hydrogen, elastic scattering is also possible.

c. Charge exchange, as per (1)

$$K^0 + p \rightarrow \bar{K}^0 + n$$

It is in these types of interactions that the K^0 meson is captured. The positive K^0 mesons display an exact correspondence to negative K^0 meson interaction types. Thus, the following K^0 meson interactions are in flight in the center.

d. Scattering:

$$K^0 + p \rightarrow K^0 + p$$

$$K^0 + n \rightarrow K^0 + n$$

e. Charge Exchange:

$$K^0 + p \rightarrow K^+ + n$$

Because K^0 mesons have a stronger value of Q , they are forbidden from undergoing absorption in reactions with nucleons.

the types (1) through (7) listed for K^- mesons. Thus, a K^+ meson that comes to rest in matter suffers Coulomb exclusion from the surrounding nuclei and can only decay (via any one of several decay modes).

Interactions in Flight versus Absorptions at Rest

In the published literature only a limited attempt has been made to compare K^- in flight behavior and K^- absorptions at rest [13]. This condition has been dictated by statistics, because in the energy region explored, the preponderance of K^- events in emulsion have been the absorptions of K^- mesons that have come to rest.

Although this report significantly increases the published statistics for in-flight interactions, the significance is still such as to permit only limited qualitative comparison. No doubt the immediate future will see the issuance of many data now in the incubation stage. Then, quantitative comparisons can be made.

Prong Distribution

Figure 1 is a comparison of the prong distributions produced by K^- absorptions at rest and K^- interactions in flight. The "at rest" portion is the published compilation of the 1956 Rochester Conference (449 events) [13]. The "in flight" portion represents an improvement of the Rochester data (where 56 events were reported from five separate research groups) by the addition of the 77 events of this report.

Two points can be made from this comparison:

- (1) The increase in \bar{N} , the average number of prongs per star, for stars in flight reflects an increase in nuclear excitation in these events.
- (2) There is justification for the premise that charge exchange is not a very large part of the K^- absorption cross section because there is no increase (in fact, there is a percentage decrease) in the number of stars with zero or one prong.

the type (1) through (4) water, and (5) in the case of the type (6) comes to rest in water surface (6) and exclusion from the surrounding air and can only decay (or decay) of water level.

Interactions in Flight versus Absorption

In the published literature only a limited number of studies have been made to compare K^+ in flight with K^+ absorption. K^+ absorption is a test of the condition of the body of the animal, and is a measure of the condition of the body of the animal. K^+ absorption is a test of the condition of the body of the animal, and is a measure of the condition of the body of the animal.

Although this is a very important factor in the study of the condition of the body of the animal, it is not the only factor. The condition of the body of the animal is a function of many factors, and the condition of the body of the animal is a function of many factors. The condition of the body of the animal is a function of many factors, and the condition of the body of the animal is a function of many factors.

Prog D Distribution

Figure 1 is a comparison of the prog distributions of the K^+ absorption, K^+ and K^+ in flight. The K^+ absorption is a test of the condition of the body of the animal, and is a measure of the condition of the body of the animal. The K^+ absorption is a test of the condition of the body of the animal, and is a measure of the condition of the body of the animal.

Two points can be made from the above:

- (1) The average number of groups per state is 1.0.
- (2) The average number of groups per state is 1.0.

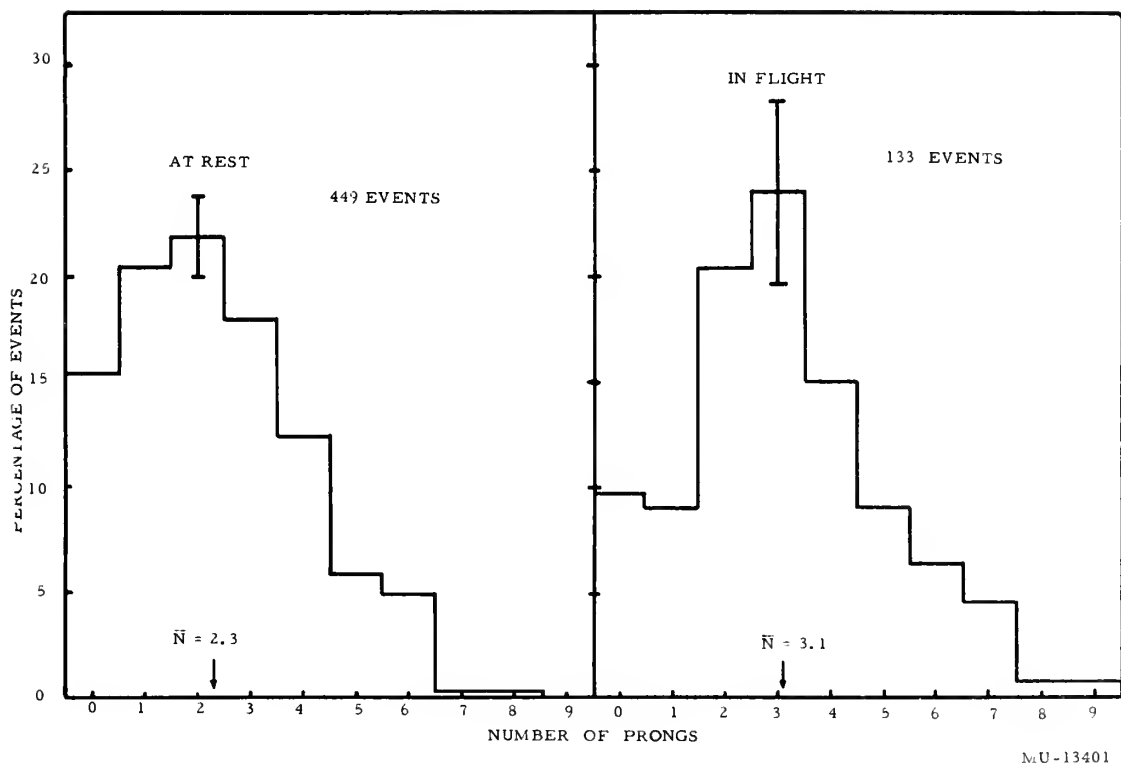


Fig. 1. Prong distributions for K^- -meson events at rest and in flight.

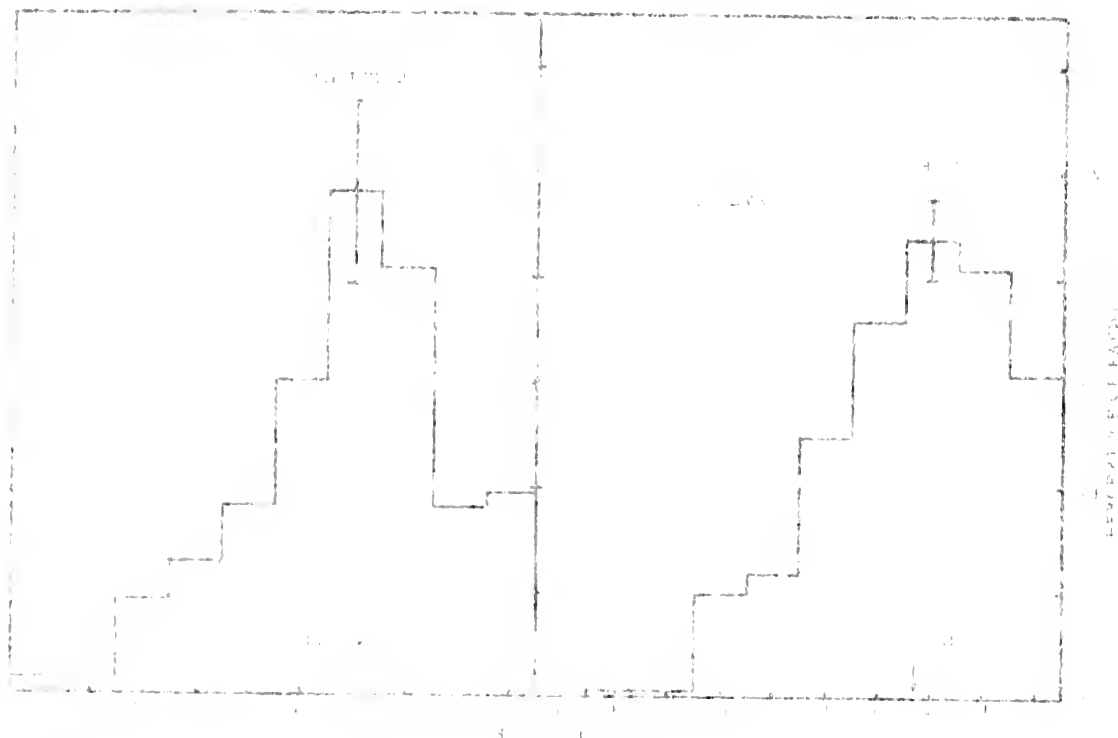


Fig. 1. Proportion distribution of release events at 100 and 200 Hz.

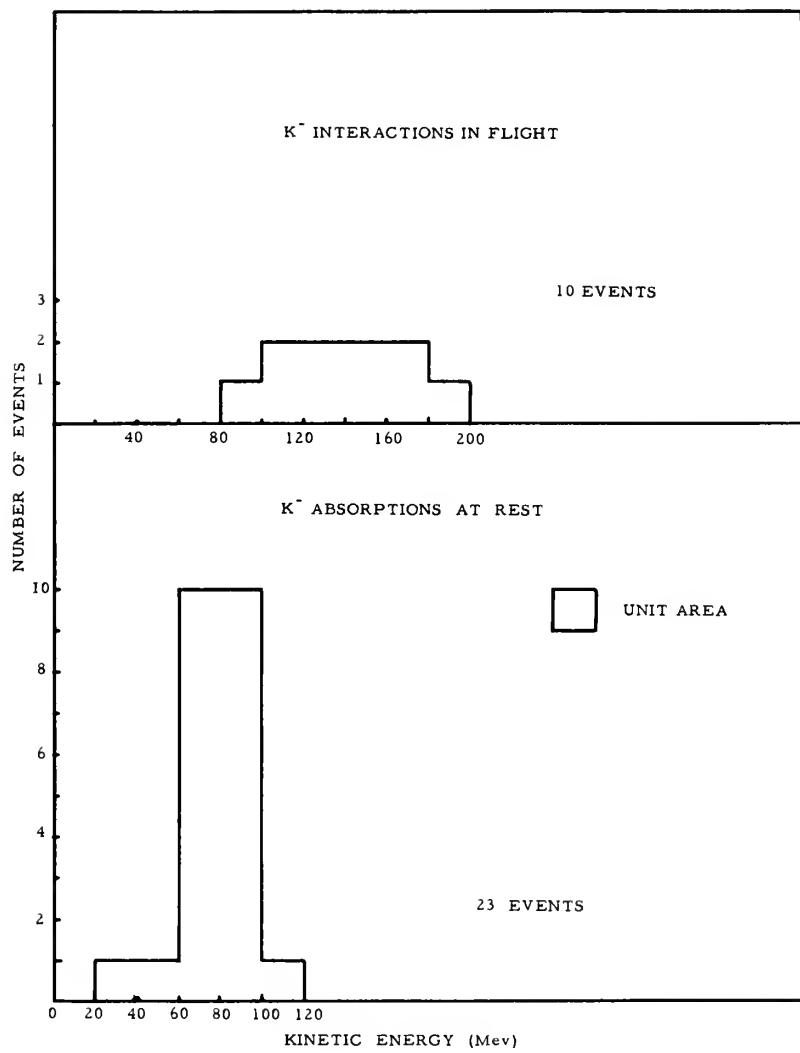
Effects of K^- -Meson Kinetic Energy

The average kinetic energy at interaction of the 77 K^- mesons of this report was 105 Mev. Because one is looking for comparative effects between K^- interactions in flight and K^- absorptions at rest, an obvious effect is to see how (or whether) this 105 Mev asserts itself. The increase in \bar{N} in the previous prong distribution is doubtless one effect. Again, one must bear in mind the limited in-flight statistics.

Thirteen of the in-flight events produced single charged hyperons, and ten of these events exhibited an associated π meson. Only one of these ten constituted an interaction with a free proton; the other nine events occur with bound protons.

Figure 2 shows a comparison of the total kinetic energy of $\Sigma + \pi$ combinations for in-flight interactions and at-rest absorptions. The approximate mean energies of each distribution are, respectively, 140 and 80 Mev. The Q available from the general reaction $K^- + \text{nucleon} \rightarrow \Sigma + \pi$ is about 104 Mev. The "at rest" distribution forms a peak at about 80 Mev, which means that the Σ and π succeed in escaping the reaction volume with about 80 Mev of their original 104 Mev. The difference in energy goes into nuclear excitation, and possible inelastic scattering losses of the particles while still in the dense nuclear region.

The "in flight" portion of Fig. 2, then, would indicate that the primary reaction products carry off an additional 60 Mev of the now-available 105 Mev of kinetic energy, the remainder of this kinetic energy going into increased nuclear excitation (as indicated in the prong distribution, Fig. 1). The use of these specific energy figures is meant to convey the degree or apparent order of the effect seen, rather than to mean anything truly quantitative.



MU-13402

Fig. 2. Comparison of sums of kinetic energies of associated Σ and π .

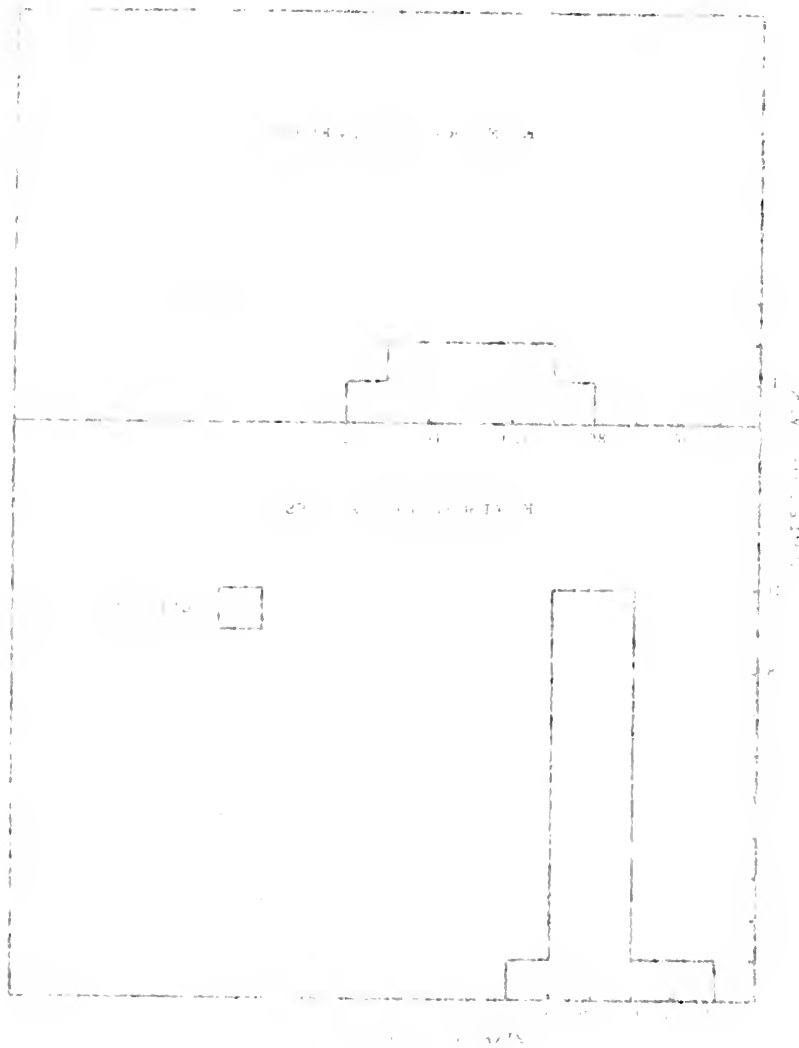


FIG. 1. A perspective view of the mechanical part shown in the top and side views. The part is a rectangular block with a central vertical section and two horizontal sections at the ends. The dimensions are 100 units in length and 50 units in height.

Total Visible Energy Spectrum

Figure 3 is another comparative distribution, this time showing the total visible energy spectra. The following constitute the criteria for energy-value assignments:

(1) All charged stable prongs were assigned kinetic energies on the basis of an assumed protonic mass from their measured ranges. In each case, then, 8 Mev of binding energy was added (a minimum amount of energy necessary to remove a proton from the nucleus). As previously pointed out, this procedure actually sets a lower limit to approximately one third of this portion of the spectra.

(2) Pi mesons were assigned their measured kinetic energies plus a rest mass energy of 139.5 Mev.

(3) Hyperons were assigned their measured kinetic energies plus a Q value taken as the difference between the hyperon mass and the proton mass, i. e., 1189 Mev minus 938 Mev, which equals 251 Mev.

Bearing in mind, again, the difference in number of events at rest and in flight, one notices the following:

(a) The percentage decrease in the number of stars with less than 20 Mev. This is to be expected since it would take only a portion of the available 105 Mev of K^- meson kinetic energy going into increased nuclear excitation, to bring about this low energy shift.

(b) The identified $\Sigma + \pi$ events (cross-hatched) assert themselves at the extreme right of each distribution. The "in flight" events shift almost as a block, as previously indicated in Fig. 2.

One would expect some fraction, say about half, of the 105 Mev of average K^- kinetic energy to appear as a general translational effect along the entire length of the "in flight" distribution. Qualitatively, such an effect is observed.

Total View of Figure 3

Figure 3 is a plot of energy versus position. The total energy spectrum is shown in the upper part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

(1) All charged particle spectra were assigned to the energy spectrum. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

(2) The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

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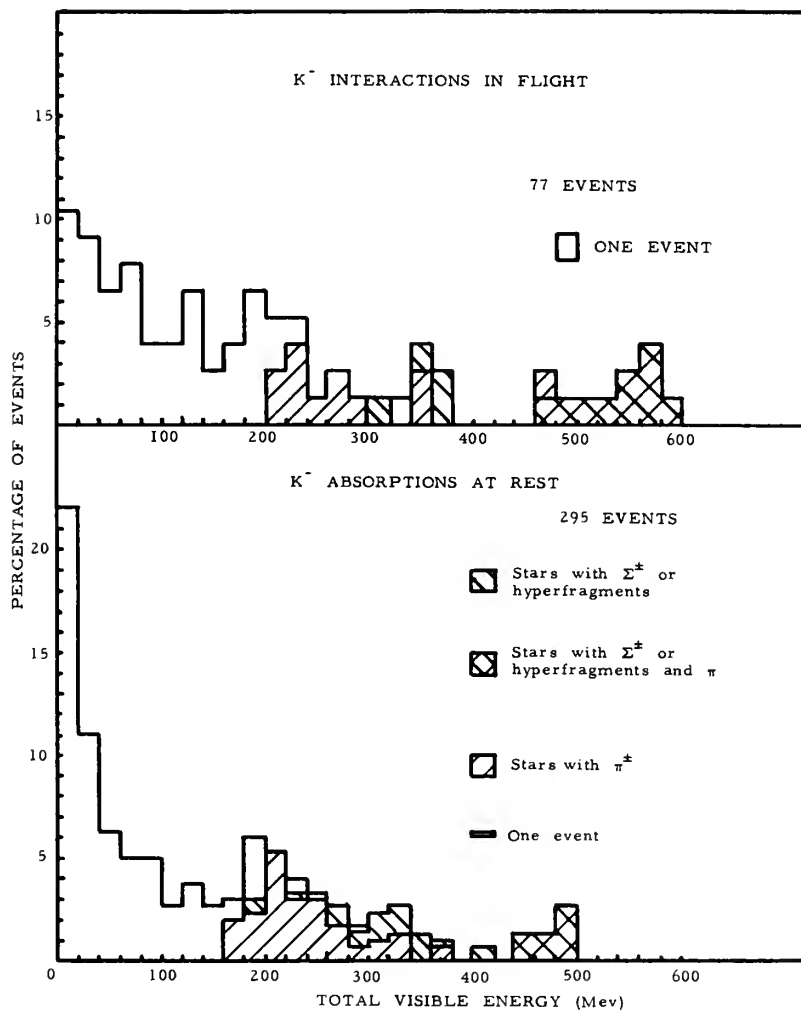
(4) The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

(5) The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

(6) The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

(7) The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.

(8) The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure. The energy spectrum is shown in the lower part of the figure.



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Fig. 3. Comparison of total visible energy release.

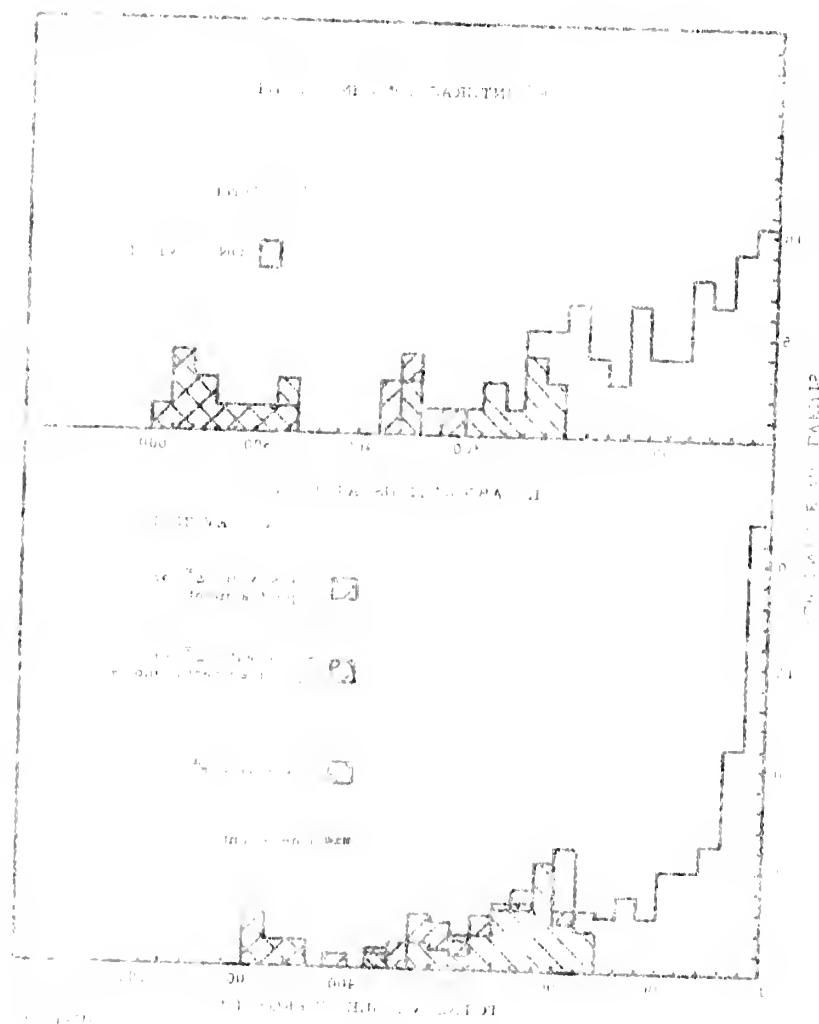


Fig. 3. Comparison of the number of releases for different categories.

The Pi-Meson Spectrum

Of considerable interest in the general study of K mesons is a determination of the frequency with which K^- mesons interact in the several available channels. A first approach would be to determine the $\Sigma^{\pm 0}/\Lambda^0$ production ratio. Because the Λ^0 hyperon will not register in the investigative medium, one must try to deduce this ratio from associated conditions that can be observed. This means that the observed charged-pion spectrum can be quite meaningful.

The statistics of the π -meson spectrum from K^- absorptions at rest are now quite good. Figure 4 shows a histogram of 169 such pions [9].

The π mesons produced in the free-nucleon capture of a K^- meson have characteristic kinetic energies of 90 or 150 Mev, depending upon whether the associated hyperon is a Σ or Λ . Figure 4 clearly displays a peak at 60 Mev both for the over-all distribution and for those pions produced in association with charged hyperons. This coincidence of peaks makes a very strong argument for the preferred production of energy-degraded 90-Mev π mesons produced in the $\Sigma + \pi$ reaction (as opposed to the $\Lambda + \pi$ type of reaction).

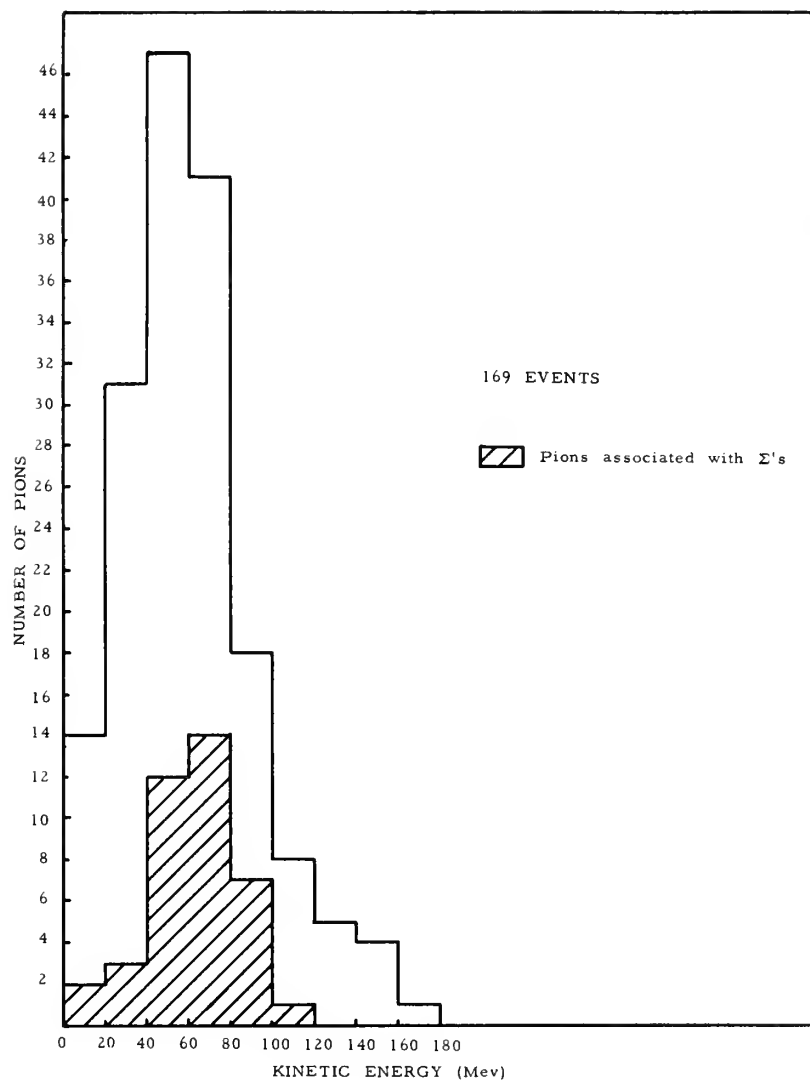
Figure 5 is a constant-area histogram showing the kinetic-energy distribution of the 22 charged pions observed from the 77 in-flight interactions of this report. The pion energies were determined by ranges where possible, or by grain count if the particle left the emulsion stack.

This spectrum of pions from the in-flight interactions is based on relatively poor statistics, but it does have one feature that subtly enhances the contention that Σ production is significantly preferred to Λ production; specifically, the pronounced high-energy peaking shows that higher-energy π mesons are not excluded from making their presence felt, if they are produced in the first place. This tends to

The first of these is the fact that the Hindu religion is not a religion of dogma, but a religion of experience. It is a religion which is based on the experience of the individual, and which is not based on the authority of any external power. The second of these is the fact that the Hindu religion is not a religion of ritual, but a religion of action. It is a religion which is based on the action of the individual, and which is not based on the performance of any external ritual. The third of these is the fact that the Hindu religion is not a religion of caste, but a religion of unity. It is a religion which is based on the unity of all things, and which is not based on the division of things into castes.

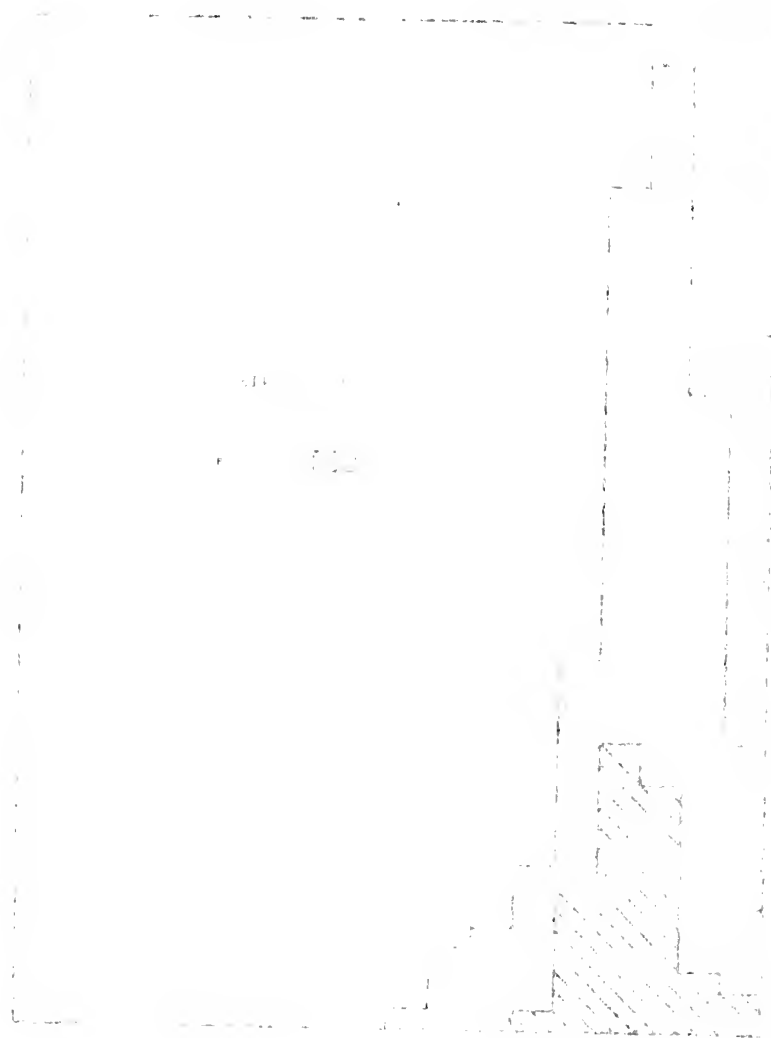
The fourth of these is the fact that the Hindu religion is not a religion of fear, but a religion of love. It is a religion which is based on the love of God, and which is not based on the fear of God. The fifth of these is the fact that the Hindu religion is not a religion of death, but a religion of life. It is a religion which is based on the life of the individual, and which is not based on the death of the individual. The sixth of these is the fact that the Hindu religion is not a religion of the future, but a religion of the present. It is a religion which is based on the present moment, and which is not based on the future. The seventh of these is the fact that the Hindu religion is not a religion of the individual, but a religion of the community. It is a religion which is based on the community of all things, and which is not based on the individuality of things.

The eighth of these is the fact that the Hindu religion is not a religion of the past, but a religion of the future. It is a religion which is based on the future, and which is not based on the past. The ninth of these is the fact that the Hindu religion is not a religion of the world, but a religion of the universe. It is a religion which is based on the universe, and which is not based on the world. The tenth of these is the fact that the Hindu religion is not a religion of the material, but a religion of the spiritual. It is a religion which is based on the spiritual, and which is not based on the material.

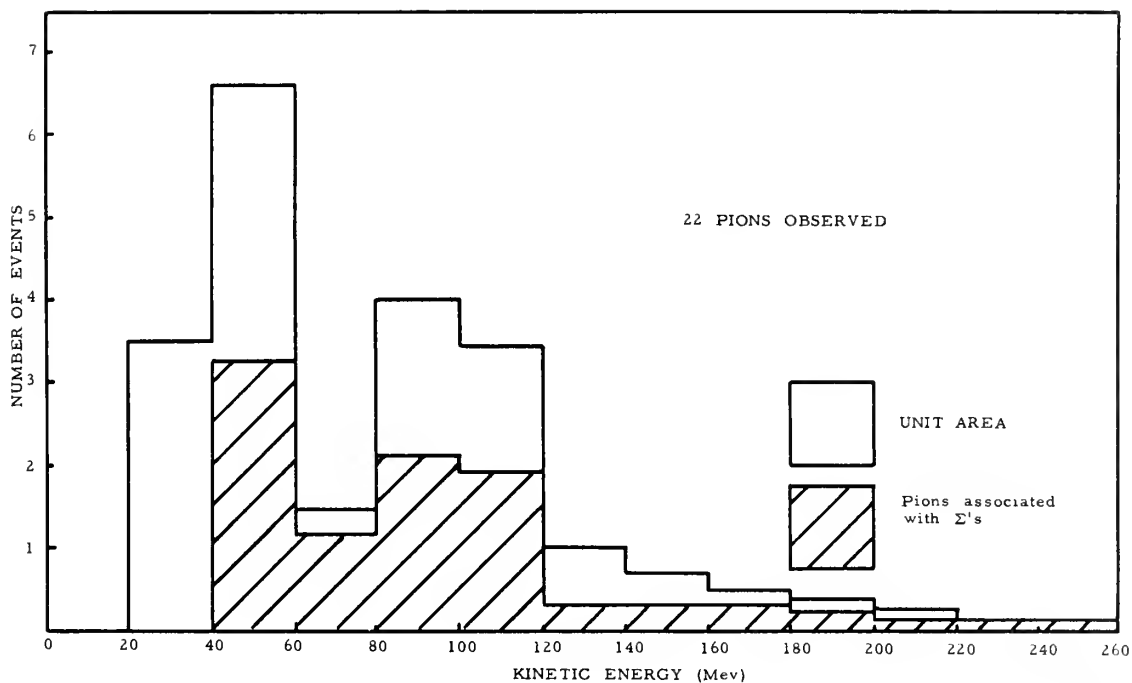


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Fig. 4. Pi-meson spectrum from K^- absorption stars.⁹



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Fig. 5. Kinetic-energy spectrum of π mesons from K^- interactions in flight. (Illustration is a constant-area histogram, reflecting the error in energy determination.)

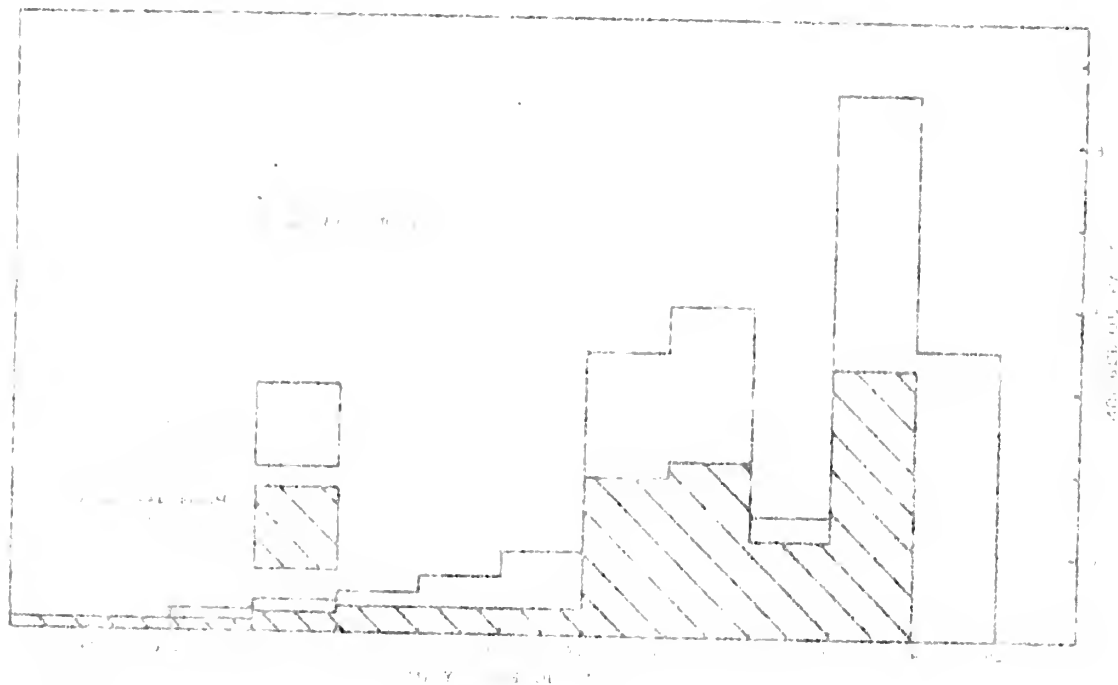


Fig. 8. Kinetic-energy spectrum of muons from K meson decays in flight. (Illustration is a constant-area histogram, reflecting the error in energy determination.)

negate arguments that have said that there is a very strong bias against the emission of high-energy pions from complex-nuclei interactions (arguments based on the peculiarities of pion scattering inside the nucleus).

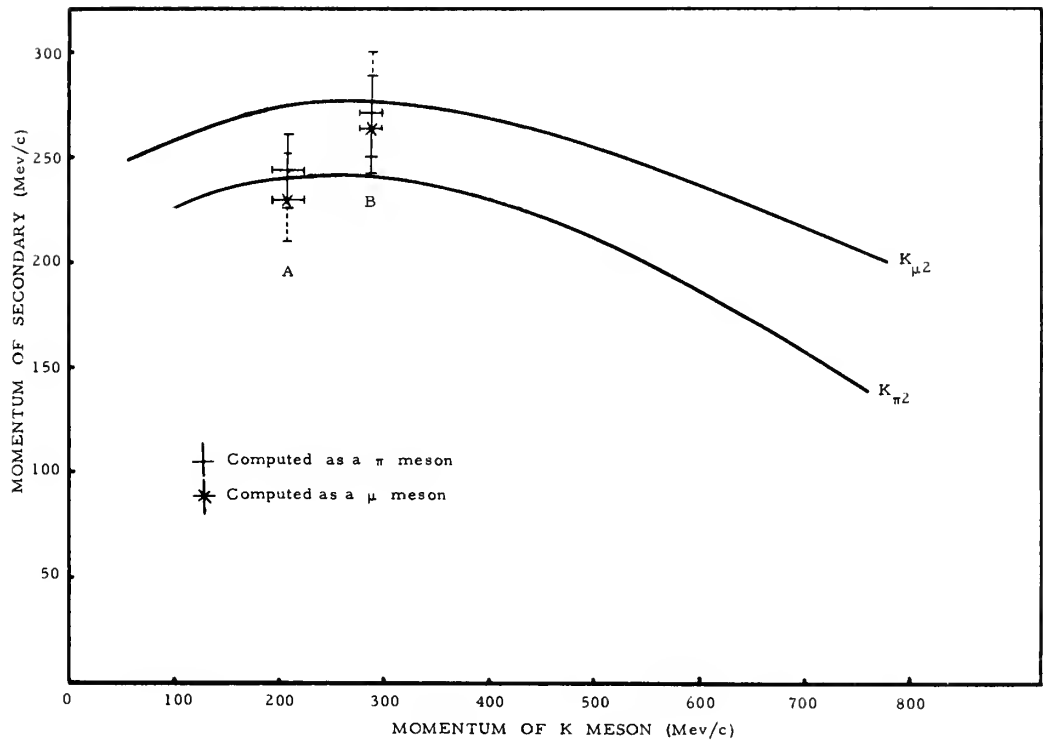
The inference, again, is that the 150-Mev pions of the $\Lambda + \pi$ reactions are infrequently produced. Thus the $\Lambda + \pi$ interaction channels for K^- mesons appear to be small.

Decays in Flight

In this study of K^- in-flight interactions, seven events were in-flight decays. An in-flight event was classified as a decay if it exhibited only one secondary prong, this prong having a degree of ionization less than that of the primary at the point of the decay. Such an event could represent an in-flight interaction with a single π -meson secondary. However, a survey of K^- absorptions at rest shows this to be a very infrequent star type (8 out of 325, in one survey) [2]. Since in-flight interactions have a much greater tendency to display evaporation prongs because of increased nuclear excitation, the frequency of occurrence of single π events is even further reduced.

Of the seven decays observed, two displayed secondaries that were amenable to measurement. One secondary was emitted at a space angle of 57.8° relative to the parent K^- meson. As Fig. 6 shows, this event (A) unambiguously resolves itself as representing the decay of a K^- meson via $K_{\pi 2}^- \rightarrow \pi^- + \pi^0$.

The second decay (B) occurred at a space angle of 57.5° relative to the K^- meson. Its kinematic resolution is not so well defined as is that of event A. Both events are displayed on Fig. 6, since they occur at nearly the same space angle. The angular error is very small ($\sim 1\%$), and this region of comparative momenta is fairly insensitive to small changes in space angle.



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Fig. 6. K^- -meson decays: momentum of the secondary particle as a function of K^- -meson momentum (for a laboratory angle of 58.0°).

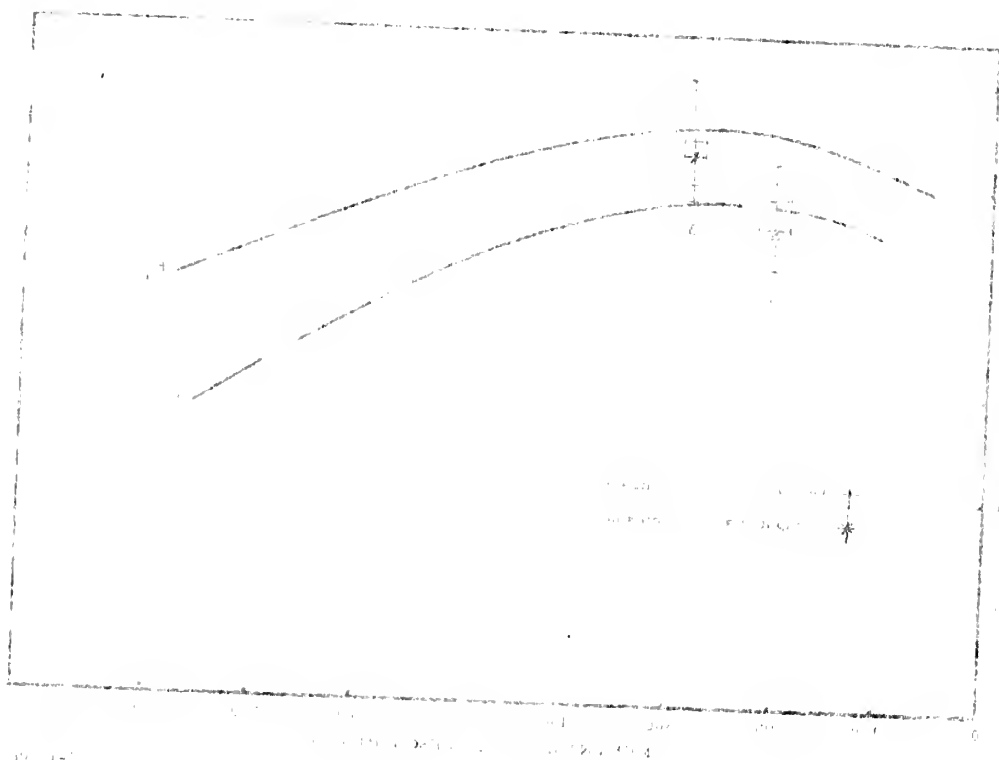


Fig. 1. K -meson decay moment of the secondary π as a function of K -meson moment (for a laboratory angle of 58.0°).

Event B is more nearly commensurate with a $K^-_{\mu 2} \rightarrow \mu^- + \nu$ decay mode, as Fig. 6 indicates. When its resolution is attempted by use of a particle of π -mesonic mass, the fit to the necessary curve ($K^-_{\pi 2}$) is worse, further strengthening the $K^-_{\mu 2}$ conclusion.

K^- Meson Inelastic Scattering

Four inelastic scatterings of K^- mesons were observed. Table II summarizes the results.

TABLE II

Results from inelastic scattering of K^- mesons		
Kinetic energy of K^- meson at scatter (Mev)	Fractional energy loss, $\Delta E/E$	Space angle of scatter (degrees)
38	0.58	55.9
58	0.62	81.8
103	0.48	58.8
138	0.55	102.8

From isotopic spin considerations, the K^- ratio of (charge exchange/inelastic scattering) is ≤ 2 . Thus, the limit on the charge-exchange contribution to the absorption cross section is $\leq 8\%$ [9].

The large fractional energy loss ($\Delta E/E$) indicates that an attractive (negative) potential may be operating in K^- scattering. In addition to the four inelastic scatterings reported here, a recent summary of emulsion data [14] indicates seven other events, all with $\Delta E/E$ greater than 0.40. This effect is the opposite of that observed in the scattering of K^+ mesons. There the energy loss in inelastic collisions is small, $\Delta E/E \approx 0.35$, which can be ascribed to a repulsive potential [15].

From the results of the experiments it was found that the rate of reaction is proportional to the concentration of the reactants. The rate of reaction is also proportional to the square of the concentration of the reactants. The rate of reaction is also proportional to the square of the concentration of the reactants.

Results from the experiments

The results from the experiments are given in Table I.

Table I. Results from the experiments

Concentration of reactants	Rate of reaction	Rate of reaction
0.01	0.01	0.01
0.02	0.04	0.04
0.03	0.09	0.09
0.04	0.16	0.16
0.05	0.25	0.25

From the results of the experiments it was found that the rate of reaction is proportional to the concentration of the reactants. The rate of reaction is also proportional to the square of the concentration of the reactants. The rate of reaction is also proportional to the square of the concentration of the reactants.

K⁻ + H Compilation

For comparative purposes, a compilation of published results of K⁻ + H scattering and absorption is given below.

Group	Energy Interval (Mev)	Absorptions in flight	Number of scatters	Path length (meters)
Goldhaber et al. [9]	16 - 160	1	1	33
White et al. [16]	16 - 150	1	10	30
Barkas et al. [17]	30 - 90	$\frac{2}{4}$	$\frac{6}{17}$	$\frac{49.5}{112.5}$

From this the following K⁻ + H cross sections have been calculated:

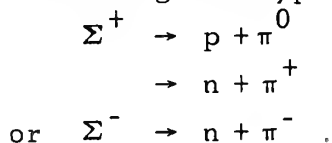
- (1) Scattering 47^{+14}_{-11} mb.
- (2) Absorption 11^{+9}_{-5} mb.
- (3) Total 58^{+16}_{-13} mb.

K⁻ Interactions in Flight: Conclusions

Within the statistics of the data of this report, there is no apparent major difference between "in flight" interactions and "at rest" interactions of K⁻ mesons in nuclear emulsion. Interactions in flight display greater nuclear excitation, attributable to the extra available kinetic energy. The inelastic scattering data indicate the presence of an attractive nuclear potential.

Σ Decay Spectrum

The charged Σ hyperons can decay via



1. The first part of the report deals with the general situation of the country. It is a very interesting and informative study of the country's development. The author has done a great deal of research and has gathered a wealth of material. The report is well written and is a valuable contribution to the study of the country's development.

2. The second part of the report deals with the economic situation of the country. It is a very interesting and informative study of the country's economic development. The author has done a great deal of research and has gathered a wealth of material. The report is well written and is a valuable contribution to the study of the country's economic development.

3. The third part of the report deals with the social situation of the country. It is a very interesting and informative study of the country's social development. The author has done a great deal of research and has gathered a wealth of material. The report is well written and is a valuable contribution to the study of the country's social development.

4. The fourth part of the report deals with the political situation of the country. It is a very interesting and informative study of the country's political development. The author has done a great deal of research and has gathered a wealth of material. The report is well written and is a valuable contribution to the study of the country's political development.

The angular distribution of these decay products with respect to the hyperon's in-flight direction can be used to investigate:

(1) Parity considerations. Lee and Yang [18] have shown that if the Σ has mixed parity, the decay spectrum should show a forward-backward asymmetry.

(2) Spin of the Σ hyperon. After the folding of such an angular distribution about 90° , one can get an indication of spin, independent of parity doublet considerations. Thus, an isotropic folded distribution would indicate a spin of $1/2$; any asymmetry would indicate a spin $> 1/2$ [19].

A survey has been made of the decays of Σ 's produced by K^- absorptions at rest and K^- interactions in flight. Thirty-seven Σ hyperons with decays have been observed. Of these, 26 were produced by K^- absorptions at rest, 11 were produced by in-flight interactions. The angular distribution of the space angle in the center of mass between the initial Σ -hyperon direction and the decay-pion direction was measured.

Figure 7 illustrates the resulting distribution, based on intervals of the cosine of the pion space angle of $1/3$, from -1 to $+1$. This corresponds to equal intervals of solid angle.

The distribution tends towards isotropy.

Σ^+ Branching Ratio

Of the 37 hyperons observed, 28 decayed at rest, thus giving a definite indication that they were Σ^+ (Σ^- interacts strongly when at rest). A Σ hyperon decaying in flight into a pion can be either Σ^+ or Σ^- . Of the 28 decays at rest, nine decayed via the $(p + \pi^0)$ mode, the other 19 via the $(n + \pi^+)$ mode. Detection of the $(n + \pi^+)$ mode in emulsion work is efficient only to about 90%. Also, only decays at rest can be reliably identified.

2) has mixed parity. The decay spectrum should show a peak at $m_{\pi^0\pi^0} = 0.77$ GeV, and a dip at $m_{\pi^0\pi^0} = 0.70$ GeV.

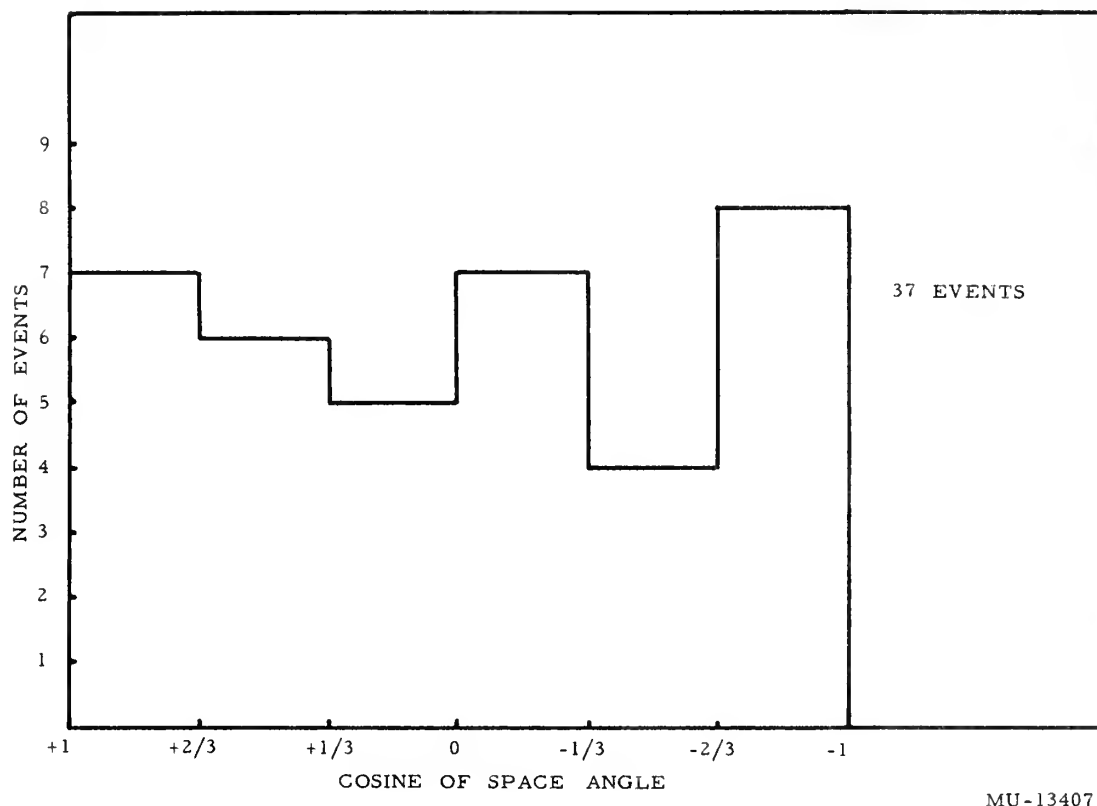
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It is noted that the distribution of the states appears to be roughly the same for both the D-hydroxy and the D-hydroxy groups. The distribution of the states appears to be roughly the same for both the D-hydroxy and the D-hydroxy groups. The distribution of the states appears to be roughly the same for both the D-hydroxy and the D-hydroxy groups.

There is a large number of different types of lamps, and the choice of lamp is determined by the type of work to be done. The most common types of lamps are incandescent, fluorescent, and LED. Incandescent lamps are the most common type of lamp, and they are used in a wide variety of applications. Fluorescent lamps are used in a wide variety of applications, and they are known for their long life and energy efficiency. LED lamps are the most energy efficient type of lamp, and they are used in a wide variety of applications. The choice of lamp is determined by the type of work to be done, the amount of light required, and the energy efficiency of the lamp.

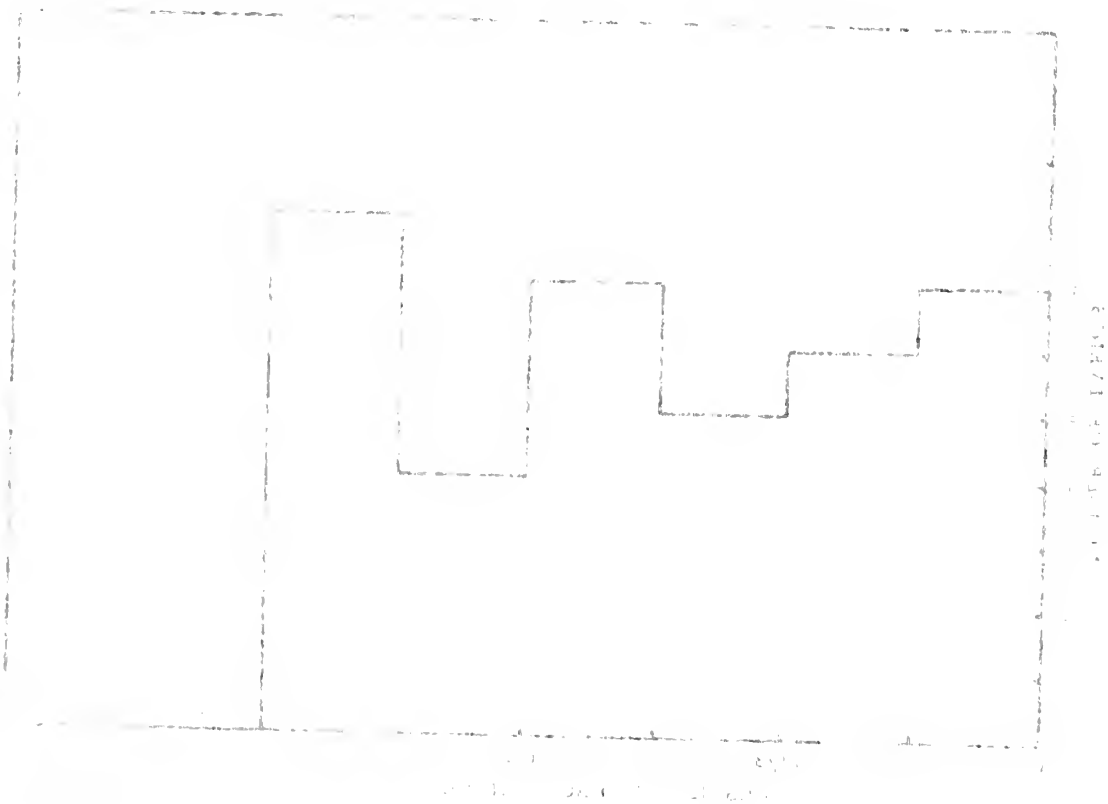
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can be reliably identified.



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Fig. 7. Angular spectrum of decay pions from hyperons produced in K^- -absorption stars. (θ is space angle between projected direction of Σ and direction of decay pion (π^+ or π^0 , as case may be) in center-of-mass system).



The graph shows the amplitude of a signal over time. The signal starts at a low level, rises to a high level, drops to a medium level, rises to a medium-high level, drops to a medium-low level, rises to a high level, drops to a medium level, and finally rises to a high level.

The published results of both emulsion and bubble chamber groups are summarized thus:

<u>Group</u>	<u>$(p + \pi^0)$ mode</u>	<u>$(n + \pi^+)$ mode</u>
Goldhaber et al. [9]	9	19
White et al. [16]	4	8
Barkas et al. [17]	13	13
Fry et al. [20]	<u>26</u>	<u>20</u>
	52	60
Corrected for efficiency	52	~ 66
Alvarez et al.	<u>27</u>	<u>31</u>
	79	97
Over-all ratio: $\Sigma_p / \Sigma_{\pi^+} = 79/97 = 0.81 \pm 0.12$		

The following are the results of the

analysis of the data obtained from the

experiments conducted under the following

Experiment No.	Time (min)	Temp (°C)
1	0	20.0 ± 0.1
2	5	20.5 ± 0.1
3	10	21.0 ± 0.1
4	15	21.5 ± 0.1
5	20	22.0 ± 0.1
6	25	22.5 ± 0.1
7	30	23.0 ± 0.1
8	35	23.5 ± 0.1

Table 1

Temp

Time (min)

ACKNOWLEDGMENTS

This work was conducted under the tutelage of Professor Gerson Goldhaber. It is but a small part of the diverse and considerable efforts in emulsion research made possible through his insight and his direction of the very capable group he has established.

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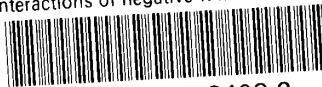
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